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13. ABSTRACT *(Maximum 200 words)*

The goal of this research is to develop stereoscopic techniques for mammographic imaging and to investigate the feasibility of using stereomemmography to improve the sensitivity of mammography for breast cancer detection, especially in dense breasts.

During this year, we have investigated the possible configurations of a stereoscopic viewing station. A prototype viewing station has been built using a PC computer with a special video processor which is interfaced to high-refresh-rate monitor and a stereo viewing goggle using liquid crystal display shutters. Although the display resolution of this prototype system is limited to a 1024 x 768 matrix of an 8-bit image, it allows us to investigate the visibility of image details of biopsied lesions and depth perception with stereoscopic imaging. We have introduced a 3-D virtual cursor into stereomammography and conducted phantom experiments to evaluate absolute depth measurement with the aid of the 3-D stereo cursor. We found that stereomammography not only improves visualization of image details, it may also be useful for absolute measurement of lesion size and depth in the breast. This may facilitate diagnostic evaluation of breast lesions.

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Chan Heang Ping   4/19/99

PI - Signature   Date

(4) Table of Contents

(5) Introduction

Mammography is the most sensitive method for detection of early breast cancer. However, 10 to 30% of the breast cancers are not detected by mammography due to various factors [1, 2]. The primary factor responsible for missed diagnosis is the camouflaging effect of overlying breast structures on a mammogram[2, 3]. This problem is most serious in dense fibroglandular breasts of younger women, but localized dense breast tissue can be commonly found in most breasts [4]. The problem is compounded by the non-linear sensitometric response of a screen-film system. The contrast sensitivity of mammography in the dense fibroglandular tissue region is low because of the low film contrast in the toe region of the sensitometric curve, further reducing the conspicuity of breast lesions. Improvement in the mammographic technique will be needed to increase the effectiveness of mammography[4].

A conventional radiograph is a projection image. The anatomical structures along the x-ray beam path are projected onto a two-dimensional image plane and overlap with each other. The overlying tissue structures often obscure the visibility of subtle lesions of interest in a radiograph. Stereoscopic imaging will allow the overlying structures to be perceived at different depths, thereby reducing the camouflaging effect. However, stereoscopic imaging has not achieved widespread acceptance in clinical practice, mainly because of the doubled film cost and increased patient exposure [5]. A secondary problem is the need to train the eyes to perceive the stereoscopic effect without aid, or to use a special stereoscope.

The recent advent of high resolution digital mammography detectors offers a new opportunity for developing low dose stereomammography. Digital detectors often have a wide linear response range so that image contrast is not limited by the detector linearity. It is possible to acquire each image in the pair at half dose of a single image technique; the increased noise may be smoothed by visual integration during stereoscopic viewing. Digital acquisition eliminates the film cost. Digital stereoscopic images can be viewed on a single display device with the assistance of a stereoscopic goggle providing an electronic shutter. The stereoscopic images can therefore be viewed singly in the conventional manner or stereoscopically on the same viewing station to provide complementary diagnostic information. Without the problem of increased patient dose or film cost, we believe that digital stereoscopic mammography will be a promising technique to improve diagnostic information for breast cancer detection.

An additional advantage of stereoscopic imaging is the 3-dimensional (3D) information it provides on the lesions of interest. It has been reported that the 3-D distribution of microcalcifications may be correlated with the malignant or benign nature of the cluster [6, 7]. Spiculations from a mass may be more readily distinguished from overlapping tissues under stereoscopic viewing conditions. This additional diagnostic information may improve the classification of malignant and benign lesions, thereby reducing unnecessary biopsies and increasing the positive predictive value of mammography.

The goal of this proposed project is to develop a digital stereoscopic imaging technique for mammography. We hypothesize that stereoscopic imaging can be a practical technique with current detector and display technology and will improve the detection and analysis of breast lesions, especially for dense breasts. The improvement results from the facts that: (1) digital imaging systems generally can provide better contrast sensitivity for imaging dense tissues, (2) the overlying dense tissue will be separated from the lesion in the stereoscopic views thereby increasing the conspicuity of the lesion, and (3) the ability to analyze the 3-dimensional distributions and shapes of lesions such as calcifications and masses within the breast can

potentially improve the accuracy of mammographic image interpretation by radiologists and reduce unnecessary biopsies.

To accomplish this goal, we will first develop an optimal imaging technique for acquisition of the stereoscopic images by using phantom studies. This includes the determination of the stereoscopic angle, the magnification factor, and the dose requirement in comparison with a single-image technique. To view the digital stereoscopic images, we will develop a stereoscopic viewing station with a high resolution monitor and implement software for panning and roaming the displayed image. A stereoscopic viewer with an LCD shutter will be used to separate the left eye and right eye images. Any one image of the stereoscopic pair can also be read independently as in a conventional single-image reading condition. It is expected that this research will result in a practical digital stereoscopic imaging technique which can improve the sensitivity of mammography for breast cancer detection, especially in dense breasts.

(6) Body

In the first year (4/20/98-4/19/99) of this grant, we have performed the following studies:

(A) Evaluation of Configuration of a Stereoscopic Viewing Station

As described in our proposal, digital stereomammograms will be acquired with a commercial Fischer biopsy system, which has a 5 cm x 5 cm CCD digital detector, in this project. In order to investigate the full capabilities of stereoscopic imaging of breast phantoms and biopsy samples, we need a workstation that is capable of displaying the 1024 x 1024 x 12-bit images from the CCD camera. We also need a high-resolution display monitor with a refresh rate of about 100 Hz to minimize flicker. During our investigation of system configurations, we found that such systems are not readily available. We performed extensive literature and Internet searches and found that almost no system can achieve these specifications. Even the Silicon Graphics (SGI) systems are only capable of displaying 1024 x 768 images at a rate of 96 Hz. The only system we found that comes close is one that employs a Sun computer with a stereo graphics board manufactured by Metheus. This system can display grayscale images with dimensions up to 1408 x 1408 at a rate of 114 Hz. However, it only displays 8-bit images and comes with very primitive display software which will require our own development of software tools such as 12-bit to 8-bit lookup tables, interpolative magnification, image cropping, and image enhancement.

While investigating these systems, we discovered many PC-based stereoscopic units that have been developed for the gaming and education industries. None of these are capable of displaying two non-interlaced 1024 x 1024 images in a page-flipping mode like the Metheus system. However, several of these systems use a technique termed synch-doubling that initially appeared very promising for our application. A synch-doubling system places an additional vertical synch pulse in the output from the graphics board. With this technique, one places the left eye image at the top of the graphics board memory and the right eye image at the bottom. The extra synch pulse occurs between the left and right eye images, which tricks the monitor into displaying them one after another at twice the normal refresh rate. To employ such a technique for our application, we would need to use a graphics board that operates in a 1024 x 2048 portrait mode. Again, we performed extensive searches, but did not find any boards that could operate on a PC computer with the desired dimensions. One of the PC systems (Neotek) offered some very useful stereo image display features that we desired for our preliminary investigations of absolute measurements of depths in digital stereomammograms described below. We therefore decided to purchase this PC-based system for our initial work and will purchase the Metheus/Sun computer system for our more comprehensive investigations during the second year of this project.

(B) DICOM image transfer

The Fischer biopsy unit that we employ to generate our digital stereomammograms outputs the images in either 8-bit TIF format or 12-bit DICOM format. The TIF images can be readily transferred to a floppy disk; however, the DICOM images are generated on the fly and sent to a DICOM server. Since we would like to study the effective signal-to-noise ratio of the stereo images and in particular determine the dose requirements relative to that of a single

mammogram, we would prefer to use the full-grayscale 12-bit DICOM images. A considerable amount of time was spent obtaining a DICOM server and setting up the parameters for the Fischer and Server such that the DICOM images could be transferred.

(C) Evaluation of Breast Lesions in Biopsied Specimens in Stereo Images

With our PC-based stereoscopic viewing station, we evaluated the visibility of image details in stereoscopic images of biopsied breast tissue specimens. The detailed structures of the breast lesions in the displayed stereo images was found to be much more conspicuous than those in a single image, as in a conventional specimen radiograph. The contrast of the subtle details appeared to be improved in the stereo display. The spiculations of the masses were more distinct from the overlapping tissue than those seen in a single image. This qualitative evaluation indicates that stereomammography is promising in improving the detection and characterization of breast lesions.

(D) Construction of a Stereoscopic Phantom for Depth Perception Study

We have built a stereoscopic phantom specifically designed for depth perception studies. A schematic drawing of the phantom is shown in Fig. 1. The phantom consists of six layers of Lexan, each 1 mm thick. On each Lexan plate, a 5 x 5 array of fibrils (0.5-mm diameter Nylon monofilaments) is set up within a 5 cm x 5 cm area. One of the layers contains 25 fibrils, one in each of the array elements. Half of the fibrils are randomly chosen to be oriented vertically and half horizontally. Each of the other five layers has 5 fibrils in randomly chosen array positions, under the constraint that no two fibrils in these five layers will occupy the same array element. The orientation of the fibril in a given array element is perpendicular to that of the first layer, forming a plus ("+") sign shape with the two fibrils at different depths. The order of the six Lexan plates can be randomly arranged so that a new phantom with fibrils of different depth spacings in different array elements can be formed. The spacing between Lexan plates can be changed by using spacers of different thicknesses. In our experiment described below, we used 1-mm-thick spacers so that, of the 25 pairs of fibrils, the spacing between each pair varied from 2 mm to 10 mm.

(E) Introduction of a 3-D Virtual Cursor to Stereomammography

A key advantage of stereoscopic viewing is the ability to discern the relative depths of objects. This property may assist the radiologist in their understanding of the 3-D nature of objects within the breast from stereomammograms. One shortcoming of conventional stereo viewing is that the absolute positions and distances between the objects cannot be determined. In an attempt to solve this problem, we conceived the idea that if one could superimpose a stereocursor on the image, one might be able to make absolute depth measurements. The cursor would be 3-D in nature. That is it could be moved "in" and "out" of the image as well as horizontally and vertically. We performed literature searches on virtual pointers and cursors and found that others have thought of this idea in the past, although for a different purpose. In particular, Drasic and Milgram of the Department of Industrial Engineering at the University of Toronto pioneered the idea of adding a stereo graphics pointer to a stereo video image. They performed tests to determine positioning accuracy using an opaque target that had the same carrot shape as the stereo pointer, but was flipped 180 degrees about a horizontal axis [8]. Their target was imaged with two video cameras. The transparency properties of our

stereomammograms are quite different from the reflective video images utilized by Drasic and Milgram, but he basic idea is the same. To our knowledge, use of a stereo pointer or cursor in stereomammography and stereoradiography has never been previously investigated.

In our discussions with companies regarding their stereoscopic viewing software and hardware, we asked if any had developed a stereographics cursor or pointer. Neotek told us they had written a stereoscopic presentation program for the Air Force that included a stereo cursor with display of the x, y, and z (depth) cursor coordinates. This presentation package was available as an option, and we purchased it along with the standard Neotek software and stereo hardware for our initial investigations.

(F) Experimental Study of the Utility of the 3-D Virtual Cursor for Depth Measurement

We performed an experiment to determine viewers' accuracy in estimating absolute positions of low-contrast fibrils in stereomammograms. For this study, we employed the phantom described previously (a 5 x 5 array of horizontal and vertical fibrils at randomized depths.) The phantom was imaged with a Fischer Mammotest x-ray unit. Left and right eye images were generated at angles of +/- 2.5°. The images were transferred to a PC computer, and displayed using the Neotek software and hardware. Three observers viewed the images and adjusted the position of a cross-shaped virtual cursor to best match the perceived location of each fibril. The z (depth) coordinate was separately calibrated using known positions of fibrils in the phantom. The observers analyzed images of two configurations of the phantom. Thus, each observer made 50 vertical and 50 horizontal filament depth measurements. In this study, the vertical fibrils were perpendicular to the stereo shift axis, and the horizontal fibrils were parallel to the stereo shift axis. The observers' measurements were compared with the true depths.

Graphs depicting the best and worst observer results for the measured vs. true positions of the vertical fibrils are shown in Figure 2. Graphs for the horizontal fibrils are shown in Figure 3. The correlation coefficients (r-values) between the measured and true depths of the vertically oriented fibrils for the 3 observers (each averaged for the two images analyzed) were 0.99, 0.97, and 0.89 with standard errors of the estimates (again averaged for the two images analyzed) of 0.39 mm, 0.86 mm, and 1.39 mm. Corresponding values for the horizontally oriented fibrils were 0.91, 0.28, and 0.08, and 1.91 mm, 4.37 mm, and 3.33 mm, respectively.

We conclude from this study that all observers could estimate the absolute depths of vertically oriented objects fairly accurately (within about 1 mm) in digital stereomammograms. However, only one observer was able to accurately estimate the depths of horizontally oriented objects. This may be related to different aptitudes for stereoscopic visualization of the observers. The orientations of most objects in actual mammograms are combinations of horizontal and vertical. Further studies will be performed in the second year to evaluate absolute depth measurements of fibrils oriented at various intermediate angles and of objects of different shapes. The effects of the shape and contrast of the virtual cursor on the accuracy of the depth measurements will also be investigated. Stereomammograms may therefore be useful not only for reducing the camouflaging effects of overlapping tissue in lesion detection, but also for allowing absolute measurements of lesion size and depth in the breast. We have submitted an abstract describing our stereo cursor study for presentation at the 1999 RSNA meeting [9].

(G) Illustrations

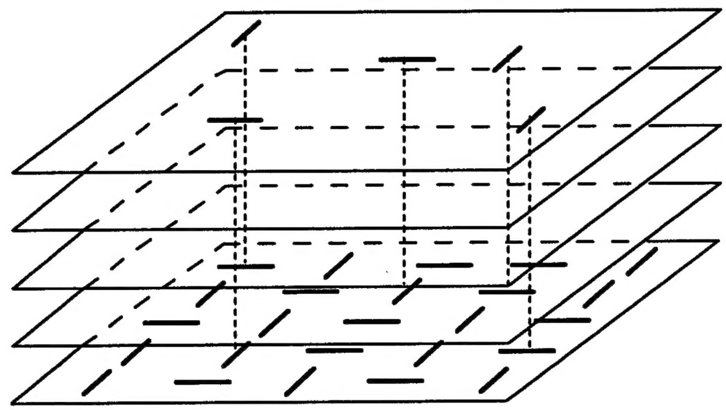

Figure 1. A schematic representation of the stereo phantom with simulated fibrils for study of stereoscopic 3-D depth perception. In the actual phantom, there are six layers of 1-mm-thick Lexan plates. The Lexan plates are evenly spaced from each other at a distance of 1 mm. One of the layers is superimposed with a 5 X 5 array of fibrils randomly oriented in two directions. Each of the other five layers has 5 fibrils placed at randomly chosen locations, with the constraint that no more than 2 fibrils will line up in the same location. The two fibrils at the same location are always oriented perpendicular to each other. For clarity, only the 5 fibrils in the top layer are drawn. The advantages of this phantom design is that other variations of a given phantom can be obtained simply by changing the spacing between the Lexan plates, or by changing the order of the six layers to vary the spacing between the test objects at a given location. A large number of phantom images with random spacing can then be generated efficiently for observer performance studies.

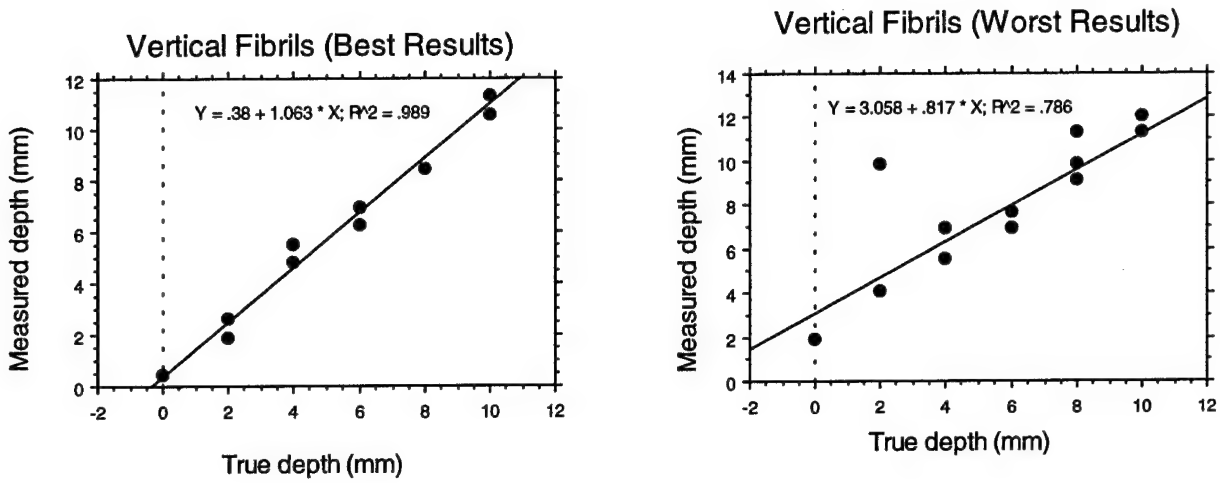

Figure 2. Depth measurement with a virtual 3-D cursor: Graphs depicting best and worst observer results in measuring the depths of vertically oriented fibrils.

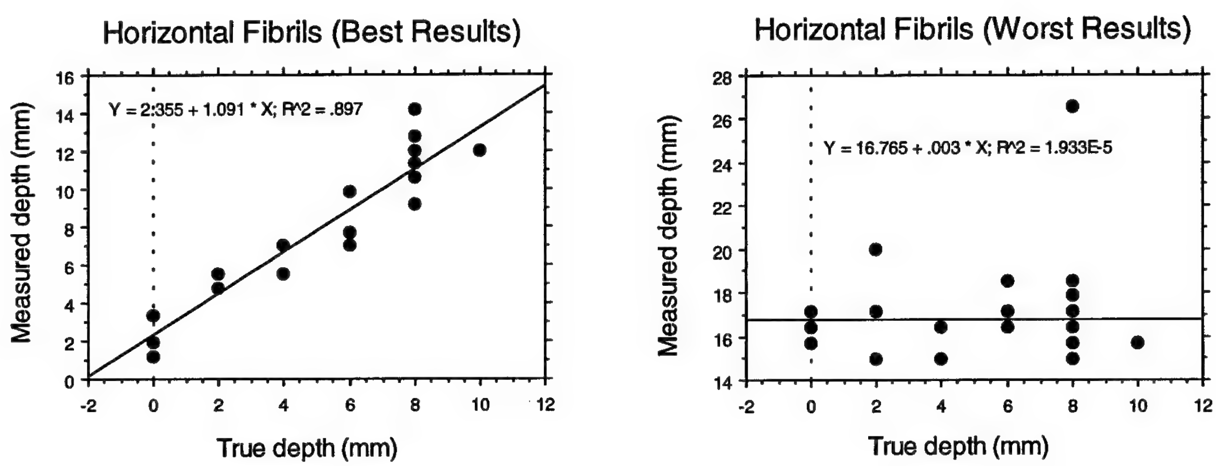

Figure 3. Depth measurement with a virtual 3-D cursor: Graphs depicting best and worst observer results in measuring the depths of horizontally oriented fibrils.

(7) Conclusion

During this year, we have investigated the possible configurations of a stereoscopic viewing station. A prototype viewing station has been built using a PC computer with a special video board which is interfaced to high-refresh-rate monitor and a stereo viewing goggle using liquid crystal display (LCD) shutters. Although the display resolution of this prototype viewing station is limited by the video board to a (1024X768) matrix of an 8-bit image, we have investigated the visibility of image details of breast lesions in biopsied specimens and depth perception with stereoscopic imaging. We have also introduced a 3-D virtual cursor into stereomammography and conducted phantom experiments to evaluate absolute depth measurement with the aid of the 3-D stereo cursor. We found that stereomammography not only improves visualization of image details, it may also be useful for absolute measurement of lesion size and depth in the breast. This may facilitate diagnostic evaluation of breast lesions.

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(9) Appendix

Publications in current year as a result of this grant

M. M. Goodsitt, H. P. Chan and L. M. Hadjiiski, "Stereomammography: Evaluation of Depth Perception Using a Virtual 3-D Cursor," Submitted for presentation at the 85th Scientific Assembly and Annual Meeting of the Radiological Society of North America, Chicago, IL (1999).

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Title:

Stereomammography: Evaluation of Depth Perception Using a Virtual 3-D Cursor

Abstract:

PURPOSE: We are evaluating the usefulness of stereomammography in improving breast cancer diagnosis. One area we are investigating is whether the improved depth perception associated with stereomammography might be significantly enhanced with the use of a virtual 3-D cursor. A study was performed to evaluate the accuracy of absolute depth measurements made in stereomammograms with such a cursor.

METHOD/MATERIALS: A biopsy unit was used to produce digital stereo images of a phantom containing 50 low contrast fibrils (0.5 mm diameter monofilaments) at depths ranging from 0 to 10 mm, with a minimum spacing of 2 mm. Half the fibrils were oriented perpendicular (vertical) and half parallel (horizontal) to the stereo shift direction. The depth and orientation of each fibril were randomized, and the horizontal and vertical fibrils crossed simulating overlapping structures in a breast image. Left and right eye images were generated at angles of +/- 2.5 degrees. Three observers viewed these images on a computer display with stereo glasses and adjusted the position of a cross-shaped virtual cursor to best match the perceived location of each fibril. The x, y and z positions of the cursor were indicated on the display. The z (depth) coordinate was separately calibrated using known positions of fibrils in the phantom. The observers analyzed images of two configurations of the phantom. Thus, each observer made 50 vertical filament depth measurements and 50 horizontal filament depth measurements. These measurements were compared with the true depths.

RESULTS: The correlation coefficients between the measured and true depths of the vertically oriented fibrils for the 3 observers were 0.99, 0.97, and 0.89 with standard errors of the estimates of 0.39 mm, 0.86 mm, and 1.39 mm. Corresponding values for the horizontally oriented fibrils were 0.91, 0.28, and 0.08, and 1.91 mm, 4.37 mm, and 3.33 mm.

CONCLUSIONS: All observers could estimate the absolute depths of vertically oriented objects fairly accurately in digital stereomammograms; however, only one observer was able to accurately estimate the depths of horizontally oriented objects. This may relate to different aptitudes for stereoscopic visualization. The orientations of most objects in actual mammograms are combinations of horizontal and vertical. Further studies will be performed to evaluate absolute depth measurements of fibrils oriented at various intermediate angles and of objects of different shapes. The effects of the shape and contrast of the virtual cursor on the accuracy of the depth measurements will also be investigated.